FN-162
0106

# STUDY PAPER ON THE NAL STORAGE RING DESIGN

M. S. Livingston

July 2, 1968

General plans and a preliminary design for a future storage ring should be developed at the NAL in the near future. The storage ring should be capable of providing the maximum interaction energy available with the 200-GeV accelerator, and with the highest possible stored beam intensity. Yet plans should also provide for an earlier intermediate-energy goal based on availability of funds and the state of technical developments. This paper utilizes concepts developed during the 1967 Study Program[1], and extends them to provide a basic design which matches the desired goals and from which responsible cost estimates can be developed.

1. Master plan for the storage ring facility:

A pair of intersecting storage rings can be located outside long straight section C in the 200-GeV orbit. They can be filled, in sequence, from the main ring by a beam ejected at straight section C, utilizing one quadrant of the first ring as a transfer path when filling the second ring. Each ring will be formed of four quadrants and four straight sections of the same length. One common straight section will be used for beam-beam interactions. See Fig. 1.

The radius of the storage ring quadrants will determine the ultimate energy for beam-beam interactions. In the analysis to follow, three values of radius are chosen, from which the desired final radius can be interpolated. For purposes of discussion and illustration we use the largest chosen radius, $r_0 = 150$ meters; this radius is used in Fig. 1.

In brief summary, the stored-beam energy in this orbit would be 75 GeV if normal iron-cored magnets are used operated at 21 kilogauss, or 200 GeV if superconducting magnets are used at 70 kilogauss.

To keep dimensions small and to achieve maximum energy it is desirable to use superconducting magnets in the storage rings. The present state of development of this field suggests 40 kilogauss as a practical upper limit at present. However, it is possible to anticipate further development to higher fields in the future. In order to estimate a practical orbit size we assume an ultimate development to fields of the order of 70 kilogauss. We also assume the same circumference factor (total length/bending length) of 1.5 used by Courant, et al[1] to compute the energies. With normal iron-cored magnets having small apertures, solid iron cores and dc excitation, we use the circumference factor of 1.225 achieved in the normal bending cells of the main ring and a maximum bending field of 21 kilogauss. If the use of superconducting magnets in the storage ring proves impractical, due either to technical limitations or excessive costs, an intermediate goal can be achieved by using iron-cored magnets.

Table I gives basic orbit dimensions and energies which can be achieved for storage rings with radii of 50, 100, and 150 meters.

Table I

| | | | | |
|---|---|---|---|---|
| St. Ring radius, $r_o$ | 50. | 100. | 150. | meters |
| Str. sect. length, $L_1$ | 20. | 35. | 51.63 | meters |
| Circumference, $C = 2 r_o + 4 L_1$ | 394. | 768. | 1249.5 | meters |
| No. turns/main ring orbit | 15.7 | 8. | 5. | turns |
| Energy, at 21 kg (iron-cored) | 26. | 51. | 77. | GeV |
| 40 kg (supercond.) | 40. | 80. | 120. | GeV |
| 70 kg " | 70. | 140. | 210. | GeV |

2. Beam-beam interactions:

The storage rings each have four quadrants and four straight sections. One straight in each ring coincides with that in the other ring, in which beam-beam interactions can be produced and observed. Injection into the rings occurs in other straights, so the interaction straight is free from all equipment other than that required for bringing beams into coincidence and observing the interactions.

A set of four identical magnets can be used to displace the two beams sidewards and into $0^o/180^o$ coincidence in an interaction region between the central pair of magnets in the shared straight. See Fig. 2a. The separation between the two beams at the entrance and exit to the shared straight can be of the order of one inch, so each beam will be displaced sidewards about 1/2 inch. This initial separation determines the orbit center spacing of the storage rings. Parallel beams are produced by deflections in the first and last magnets of the storage ring quadrants on either end of the straight, which are traversed by both beams. See Fig. 2b. Instruments for observing the products of beam-beam interactions can be located at large angles outside the interaction region; or they can be located beyond the first storage ring magnets and product particles observed at very small angles which traverse the magnet gaps in the direction of the beams.

An alternate arrangement can be used in which the beams cross each other at two points within the shared straight section. See Fig. 2c. For this arrangement the two first and last magnets in the storage rings are slightly reduced in field to produce the desired small crossing angle $\theta$. And the two beams are returned to their orbits by deflection through an angle $2\ \theta$ in a common magnet at the center of the straight. Observing instruments can be located in the directions forward or backward from each interaction region to observe small-angle interactions.

The luminosities which can be achieved in beam-beam interactions depend on the space charge limits in the storage rings and upon the various orbit parameters which determine beam dimensions and the efficiency of stacking successive injected pulses into the orbits. Following Courant, et al[1] we assume the same aperture and betatron wavelength of the CERN PS, and the same beam-stacking efficiency and stored beam dimensions as for the CERN ISR, in order to obtain comparable luminosities. We use the same space-charge limited current in the storage ring used by Courant, et al, and compute the number of protons in the rings, the space-charge limited luminosities and other results on a comparable basis. Results are given in Table II.

Table II

Space-charge limited filling times, luminosities, etc.

| | | | | |
|---|---|---|---|---|
| St. ring radius, $r_o$ | 50. | $\boxed{100.}$ | 150. | meters |
| Space-charge limits in St. R. | | $\boxed{1450.}$ | | amperes |
| No. protons in St. R. at sp-ch limit | $1.0\times10^{16}$ | $\boxed{1.9\times10^{16}}$ | $3.0\times10^{16}$ | p's |
| Charge/pulse from main ring | | $\boxed{5\times10^{13}}$ | | p's/pulse |
| Charge/min at pulsing rate of 20/min | | $1.0\times10^{15}$ | | p's/min |
| Filling time for St. R. (each) | 10. | 19. | 30. | minutes |
| *Luminosity, sp. ch.-limited | $1.2\times10^{35}$ | $1.2\times10^{35}$ | $1.2\times10^{35}$ | $cm^{-2}sec^{-1}$ |

*Luminosities are calculated from the example cited in Courant, et al[1], of $L = 7\times10^{32}/cm^2sec$ for $1\times10^{16}$ p's in a 100 m storage ring and $2\times10^{15}$ p's in the main ring orbit of 8-times larger orbit. The numbers in boxes in Table II are taken directly from Courant, et al.

3. Comparison with bypass-storage-ring system:

Courant, et al[1] propose a bypass-storage-ring system in which beam pulses from the accelerator are first stored in a small storage ring, then the main ring magnet is switched to the dc mode of operation, part of the stored beam is switched back into the main ring, and interactions occur between the stored beams in the storage ring and the main ring. They compute the luminosities available with such a system to be equivalent to or higher than the design luminosity of the CERN ISR. In order to fill the small ring and switch back into the main ring, bypass sectors are used to direct the beam from straight section B into the small ring, and to re-enter the main ring orbit in straight section D. An important feature of this scheme is the opportunity of increasing the energy of the stored beam in the main ring by slow synchronous acceleration, to energies up to 200 GeV, allowing beam-beam interactions at 50/200 or 100/200 GeV energy.

Comparison of the dual storage ring system proposed here with the bypass storage ring system shows many advantages for the dual ring system:

a) Interactions will be avilable from 75/75 to 200/200 GeV energies depending on the level of success in development of superconducting magnets for the dual ring.

b) Luminosities (space-charge limited) will be larger in the dual ring by a factor which is four times the ratio of main ring orbit circumference to storage ring orbit circumference.

c) Bypass sectors from straight sections B and D are not required for the dual ring system. Only a short straight bypass is needed for storage ring filling.

d) The beam-beam interaction region is located in an otherwise unused shared straight section in the dual ring system, so experimental set-ups and developments will not interfere with other activities in the laboratory.

e) Once the storage rings are filled the accelerator can be switched back to normal operations with the emergent proton beam, during storage ring operations.

4. <u>Cost estimates</u>:

Costs can be estimated on the assumption that they will not exceed those for a storage ring system built of normal iron-cored magnets. The special features are the dc-powered, small-aperture magnets needed in the storage ring, switching systems for stacking beams in the storage rings, and the experimental hall surrounding the shared straight section used for beam-beam interactions. Other features are quite similar to designs already in process for the main accelerator, such as the enclosures for the storage ring orbits, straight section enclosures, fast ejection magnet systems for switching the beam out of the main ring, etc. Vacuum problems are understood and not significantly more stringent than for the main ring.

At some future time it will be possible to assess the practicality of using superconducting magnets in the storage rings. This decision can be based on two aspects of cryogenic developments. First, it should be demonstrated that superconducting magnets can be successfully built to operate at fields of the order of 70 kilogauss. Second, the total cost of a superconducting magnet system (construction operation and power for a period of 10 years) should be comparable with that for an iron-cored magnet system. Hopefully, this decision can be reached in adequate time to change design goals and utilize superconducting magnets.

If the criteria of selection of the superconducting system include the cost balance described above, it is not necessary to estimate costs for such a system at the present time. Rather, the costs for an iron-cored magnet system, which are essentially available at present, will become realistic costs for the superconducting system as well. So we can proceed to estimate a realistic cost for the future storage ring facility on the basis of presently known techniques and unit costs.

## REFERENCES

1. E. D. Courant, L. W. Jones, B. W. Montague, E. M. Rowe, and A. M. Sessler, Bypass-Storage Ring Option for NAL, Nucl. Instr. and Methods, 60, 29-35 (1968).

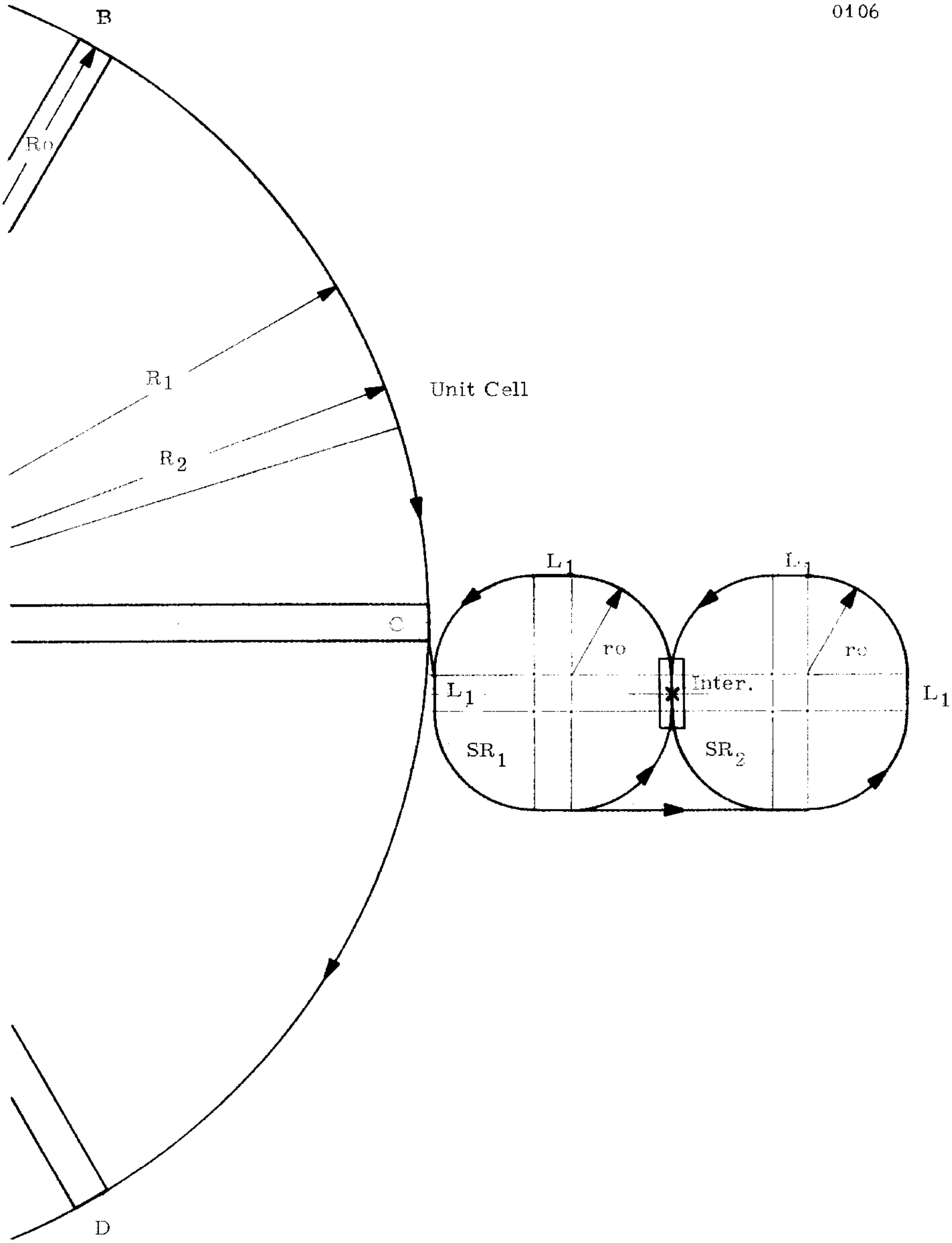



Fig. 1 - Proposed dual storage ring facility for NAL

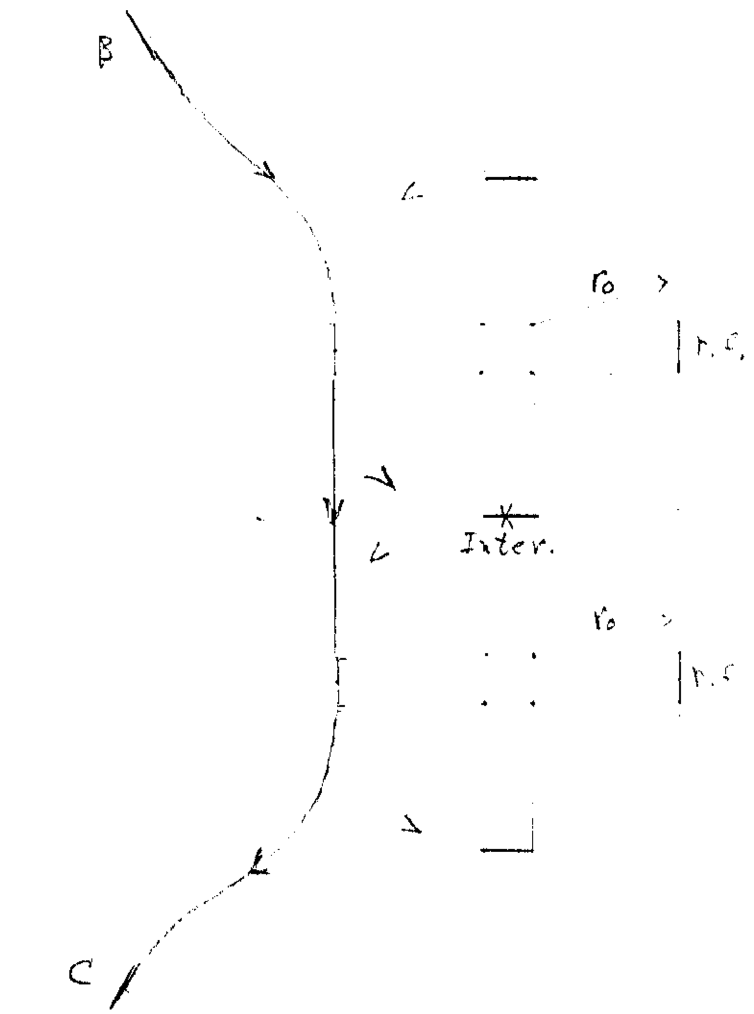
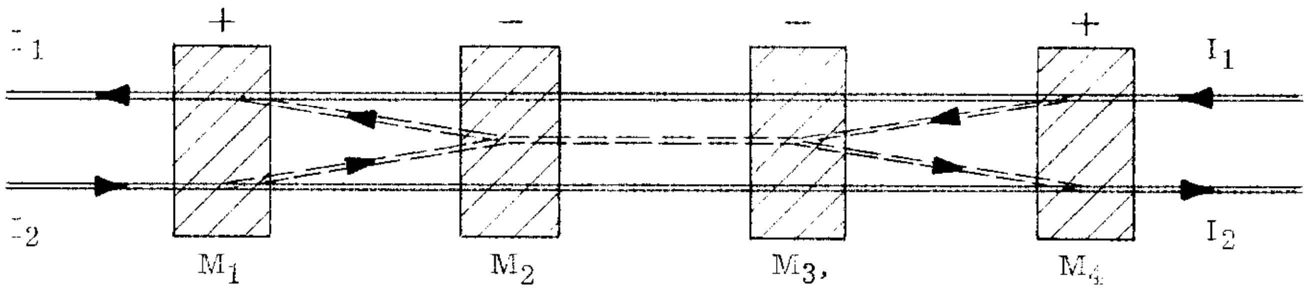
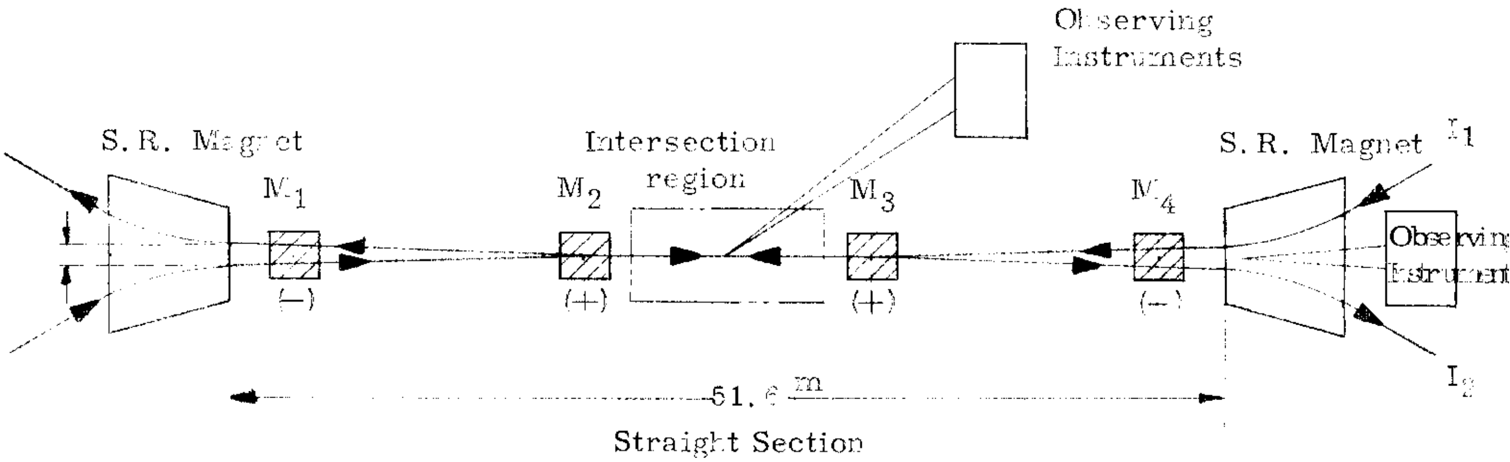


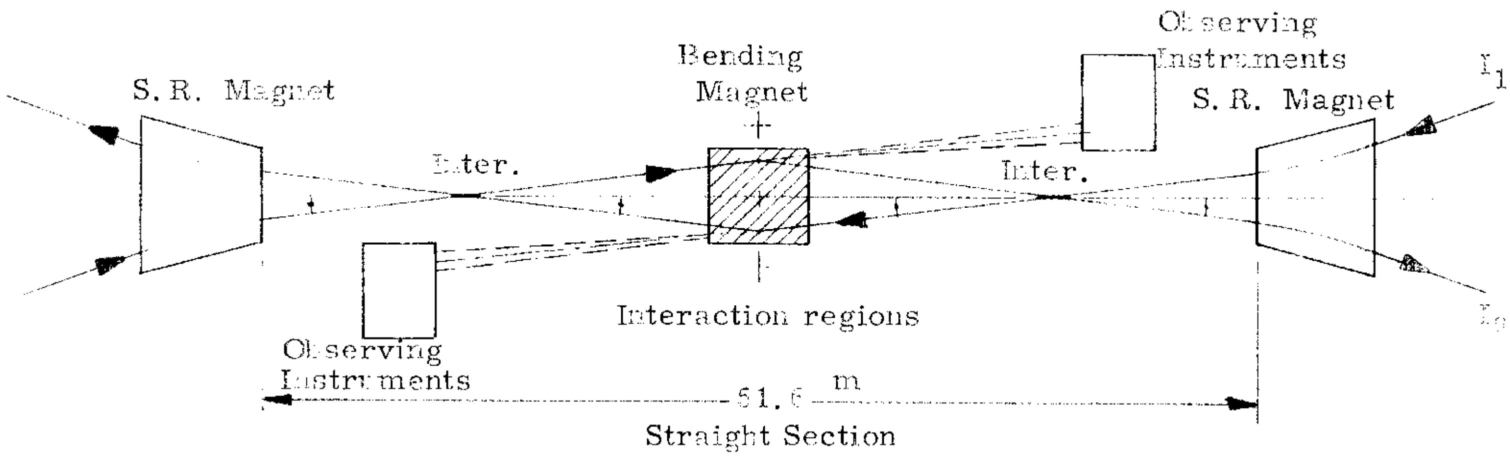

Fig. 1a. Dual Storage Ring with Bypass for NAL




a. Magnet quadruplet to produce coincidence of parallel beams




b. Arrangement for $0^o/180^o$ beam-beam studies




c. Arrangement for small angle intersection beam-beam studies

Fig. 2. Arrangements for beam-beam interaction studies